Structural Influences on Water Withdrawals: An Exploratory Macro-Comparative Analysis

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Abstract

It has been well documented that many societies around the world are currently experiencing the consequences of water scarcity, and this scarcity is likely to be one of the major resource crises of the 21st century. While environmental sociologists and human ecologists have analyzed the social forces driving a variety of biophysical impacts, the socio-structural factors influencing water consumption have not been extensively investigated. We discuss the variety of challenges facing analyses of water consumption at the national level, particularly those stemming from data limitations and the diversity of forces, both social and biophysical, which influence water use. Recognizing the limitations of conducting cross-national research on water resources, we present our analysis as exploratory. We use a simultaneous equation model to analyze the factors influencing both water withdrawals for agricultural use and withdrawals for other uses. We find that economic development and connections to the global economy are key forces influencing water consumption, where at the national level, affluence and globalization lead to a decline in agricultural water use, but an escalation of water use in other sectors.

Keywords: *water consumption, human ecology, world-systems theory, agricultural production*

Introduction

Access to freshwater has always been a central concern for human societies, and declines in water availability have at various times in human history contributed to societal collapses (Chew 2001; Diamond 2005; Ponting 1993). It has been well documented that many societies around the world are currently experiencing the consequences of water scarcity, and this scarcity is likely to be one of the major resource crises of the 21st century (Gleick 2004; Postel 1999; Shiva 2002; Homer-Dixon 1999). However, the social structural factors that influence water consumption have not been extensively investigated by social scientists, particularly sociologists.

Human social relations influence the long-term sustainability of ecosystems. In turn, ecosystems influence social conditions and the sustainability of societies. Since natural resources, especially water, are a fundamental requirement for societies, it is clearly important to understand the social forces that affect resource consumption. Early environmental sociologists working in the human ecology tradition brought this insight to the center of social scientific investigation (Catton and Dunlap 1978).

Social scientific cross-national research on global environmental issues is still in its early stages of development (Burns et al. 1997). In recent years, however, this type of research has begun to increase in scope with the growth of the sub-discipline of environmental sociology. Nonetheless, while issues such as deforestation and carbon dioxide emissions have been addressed with growing frequency (Burns et al. 1997; Dietz and Rosa 1994; Grimes and Kentor 2003; Rudel 1989; Rudel 1997), water and its sociological significance have yet to be studied in any extensive detail.

Following the human ecology tradition, this study is a cross-national investigation into the forces that influence freshwater consumption. Using a combination of social structural and environmental (biophysical) variables, we conduct quantitative analyses that explore the complexities that exist in this aspect of the societal-environmental relationship. Specifically, we aim to elucidate the structural factors that contribute to freshwater consumption in the modern world-system.

Water Resources and Water Use

While it may appear abundant, freshwater is a scarce resource. Less than 1% of all the water on earth is available freshwater (UNESCO-WWAP 2003). The United Nations reports that currently 43 nations face water stress and scarcity[3] (United Nations Development Program 2006). More than a billion people do not have access to clean drinking water, and

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almost three billion have no access to sanitation services (Magdoff 2004). Due to the present rates of population growth, pollution, consumption and diversion, water may quickly become a highly contentious resource. Some have gone so far as to venture that "Water promises be to the 21st century what oil was to the 20th century" (Tully 2000, 343). The increasing demand for water may well represent a global crisis in the making.

Global demand for water has been increasing rapidly, particularly since the end of World War II. This increase is occurring at twice the rate of population growth, doubling approximately every 20 years (OECD 1998; United Nations Development Program 2006). As a result, water resources are under stress throughout the world: rivers, streams and groundwater have been polluted with toxic chemicals, aquifers are being depleted at rates faster than they can regenerate, wetlands are being destroyed by massive urbanization (and suburbanization), climate change is altering weather patterns, and dam construction has devastated watersheds and riparian ecosystems (Gleick 2004; Gold 1999; OECD 1998; Postel 1999; UNESCO-WWAP 2003). These trends are having significant consequences for societies throughout the world, but, like many resource issues, they have greater and more devastating impacts on marginalized and poor populations (United Nations Development Program 2006).

While availability of clean fresh water resources has become a concern for all countries, access to supplies of water adequate to meet the needs of all sectors has become particularly acute in many parts of the developing world. While dry climates can often create physical limits to a population's access to fresh water resources, climate is not always a good indicator of water availability for local populations. The recent United Nations Human Development Report (2006) indicates that poverty is often associated with lack of water access even in areas that are endowed with plentiful fresh water through rainfall and groundwater. In contrast, affluent nations, even those that experience water stress, generally provide better access to water for the majority of their populations than some developing nations that have more per capita water availability (UNESCO-WWAP 2006).

The majority of the world's water is consumed in the agricultural sector, where approximately 70-75% of the water resources are used mostly for the irrigation of crops. While industry is also a large consumer of water resources, this typically only reaches substantial proportions in the developed world. On a global scale, industrial water use makes up about 15% of all water use (Gleick 2002). However, in developed nations, industry can be the largest consumer of water with withdrawal rates as high as 50-60% (Gleick 2002; World Bank 2005). In the industrial sector, water is used in a variety of processes including heating, cooling, and as a solvent or a raw material.

Although water withdrawals in this sector are not as high as withdrawals for agriculture on a global level, industrial production also has an impact on water resources through pollution and hydro-engineering (e.g., the construction of hydroelectric dams). These impacts are not necessarily considered water withdrawals, but have significant effects on water resources. Industrial pollution destroys available freshwater resources by introducing an array of toxins, heavy metals, and petroleum products into water systems.[4]

Domestic (i.e., household) water use is the smallest contributor to water withdrawals worldwide, being responsible for approximately 10% of all water consumption (Gleick 2002). Demographic changes, particularly population shifts to urban areas, are often associated with shifts in water use patterns. This growth in urban population has contributed to stress on water resources. Parts of Asia that have experienced this growth in urbanization have seen falling aquifer levels, water shortages, and high levels of pollution (UNESCO-WWAP 2003). In addition, many developing countries have experienced a sharp growth in hazardous industrial production, such as chemical and pesticide production (Frey 1998), often increasing the stress on water availability for poorer populations.

As stated above, at present almost three-quarters of the world's freshwater resources are used in the agricultural sector. The disproportionate use of water by this sector highlights the need to understand the drivers of agricultural water consumption and the impacts that the modern agricultural production system has on resources. Due to its dominance, we devote much of our analysis to the impacts of agriculture on water resources. We do so by examining the modern agricultural production system and its industrialized nature. Modern methods of production within agriculture are characterized by capital and technology intensive practices. As we will discuss below, irrigation has played an integral role in this production system.

Water and Agriculture

Food and water are of central importance to all societies. Considering this basic reality, investigating the development of agricultural production practices, specifically its impact on freshwater resources, will allow for a better understanding of the dynamics of human-environment interactions. While agriculture emerged about 10,000 years ago and irrigation around 6,000 year ago, today's food system barely resembles its distant predecessors.

In ancient times, the Tigris and Euphrates Rivers in Mesopotamia were diverted for irrigation, allowing for the further expansion of crop production in the "fertile crescent," despite the aridity of the region (Postel 1999). Water diversion and irrigation projects in early civilizations allowed for the growth of food surpluses that drastically changed social dynamics within those societies (Mazoyer and Boudart 2006; Ponting 1993). Since then, societies around the world have used irrigation to produce an abundance of crops in arid regions.

At the turn of the 19th century about 8 million hectares of land were irrigated for crop production. By the mid-20th century this expanded to 94 million hectares, and near the end of the century this total had reached more than 250 million hectares (Postel 1989). This expansion of irrigation has permitted the conversion of areas that have historically been too hot and dry for significant crop production into highly productive cropland. As a result, these areas have become major food producers for modern societies (Hunt 2004; Postel 1999).

The growth of agricultural production sparked by the post World War II "green revolution" has relied on a technology and capital intensive "package"—including large chemical inputs, mechanization, and monocropping high yield crop varieties—which was designed to work in tandem with irrigation projects. As a result, approximately 40% of food production worldwide is on irrigated lands (Gleick 2002; OECD 1998). Postel (1989, 1999) estimates that about 3,000 cubic kilometers of water are removed from the earth's rivers, streams, and underground aquifers to water crops each year. Many nations around the world have responded to increases in water demand by building more dams and diverting more waterways, which has led to the disruption of more than 60% of the world's rivers, as well as tapping groundwater at an unprecedented rate (Barlow and Clarke 2002; Burke and Moench 2000).

The industrialization of agriculture and the increasing application of chemical inputs have had degrading effects on water resources. What has developed over the past half century is a global division of labor and control of agriculture by a small group of multinational corporations (McMichael 2000). In this economic structure, regions are selected for their "comparative advantage" and pushed toward specializing in the large-scale production of a few export-oriented crops in order to integrate nations more fully into the global capitalist system (Thrupp et al. 1995). This system sets the stage for not only financial exploitation—as a few large corporate distributors, transporters, and processors accumulate an increasing share of each food dollar (Heffernan 2000)—but environmental exploitation as large-scale chemical and irrigation intensive agriculture is encouraged by world financial agencies and their corporate representatives. These processes have had a variety of impacts on freshwater resources.

Water coming from irrigation drainage often contains elevated levels of natural and synthetic compounds (National Research Council 1989). Fertilizer and pesticide run-off into freshwater sources caused by the excessive use of synthetic farm inputs has polluted water throughout the world (OECD 1998). The Environmental Protection Agency in the United States estimates that more than half of the wells in the U.S. are contaminated with pesticides and nitrates (Barlow and Clarke 2002). Synthetic fertilizer and pesticide runoff damages aquatic ecosystems and has been regularly detected in groundwater (Burke and Moench 2000) and surface waters (Gold 1999), and there is extensive evidence that many of these synthetic compounds are cancer causing agents (Coye 1986).

Groundwater is particularly susceptible to pollution in that, unlike surface water such as rivers, it is typically very slowly replenished. Deep aquifers can contain water that is thousands of years old. Agricultural production is a main source of groundwater pollution. It has been estimated that in the U.S. an aggregate of 147 million hectares of groundwater sites have been affected by agricultural pollution (Burke and Moench 2000). Irrigation has the tendency to intensify the problem. As stated in the 1998 *OECD Report on Sustainable Water Management*, "The effect of agriculture on water quality is potentially greater in irrigated areas, since the intensification of production methods and the high rate of evapo-transpiration associated with irrigation practices tends to concentrate not only farm chemicals but also those elements that occur naturally in the water source itself" (OECD 1998, 7-8).

Under certain circumstances irrigation can lead to the salinization of soil as salt is one of the elements that occur naturally in water sources. Salinization of soil comes about when water-intensive farming practices are used in regions that have high rates of evaporation because of hot and dry conditions. The high rate of evapo-transpiration necessitates more water and this cycle results in concentrated levels of salt residues left behind on the soil surface. As salt residues accumulate, they can destroy the fertility of the soil (Postel 1999; Hunt 2004).

Another significant concern related to water-intensive farming is water-logging. Water-logging occurs when land conditions, such as the slope of the land and organic make-up of the soil, do not allow adequate drainage to occur. As a result, land is saturated and the water table rises to surface levels (Postel 1999). This saturation of the soil with irrigated water starves roots of needed oxygen and kills crops. India and Pakistan suffer from possibly the worst cases of water-logging in the world (Burke and Moench 2000). It is not a coincidence that they top the list of nations in land irrigated per year, along with the U.S. (World Bank 2005). In the U.S. about 25% of irrigated land suffers from salinization and/or water-logging (Shiva 2002). It is worth noting that the demise of Sumerian civilization was brought about in part due to water-logging and salinization (Foster 1994; Mazoyer and Boudart 2006).

Over-consumption and pollution of this precious resource has had, and will continue to have, profound social effects. As water stressed regions increase, understanding the underlying social mechanisms that affect water usage is crucial for the development of strategies to meet the world's water needs (OECD 1998; Shiva 2002; United Nations Development Program 2006). Social scientists should play a key role in addressing these socio-ecological issues (Burns et al. 1997).

The Human Ecology of Water

One of the main problems of assessing the driving forces of resource depletion and pollution in the modern globalized world is that trade relations geographically separated causes from effects. As discussed above, a key insight of human ecology is that societies are affected by their biophysical environments. However, connecting biophysical context to particular social processes becomes challenging in a world characterized by the global mass production and consumption of goods and services.

While some natural resources, such as oil, flow relatively friction free throughout the global economy, this is not true of water. A society need not have oil reserves in its territory to be a mass consumer of oil because oil is readily available on the global market. Because of oil's relatively high value per unit of mass, it is economically practicable to import and export oil resources. Water, however, is different since in the volumes necessary for agricultural production and other large scale uses, it is impractical to transport it long distances (except via "natural" transportation—e.g., rivers).[5] Thus, the water use of societies is more likely to be connected to the local biophysical environment than is the use of other resources such as oil. Analyzing water consumption in a sociological context and drawing on the human ecology tradition should allow for an increased understanding of the interactive relationships between the local biophysical environment and social relations.

Data and Methods

Here we perform a cross-national analysis of the structural factors that influence water withdrawals. There are several challenges to analyzing the structural factors that influence water consumption at the national level. First and foremost, the best available data on water withdrawals at the national level for most nations in the world is of dubious quality and not available in consistent time-series. Generally, it is understood that obtaining and recording reliable data on water supply and withdrawals is difficult (Gleick 2004). Moreover, while tracking water use can be challenging all over the world, it is often a greater concern in developing countries. For example, in order to calculate how much water is used for irrigation, public ministries often estimate how much land is irrigated, and from these estimates calculate water use (Brown 2002).

Here, we use the estimates of freshwater withdrawals circa 2000 presented in Gleick (2004), which are the best available. Gleick (2004, 257) notes that "these detailed country data should be viewed, and used, with caution. The data come from different sources and were estimated over different periods." For this reason, we present our analysis here as only a first step, which aims to give some sense of the factors associated with national-level water consumption. Considering the limitations of the data, our results are only suggestive of the associations among factors and the processes occurring. Future analyses, as better data become available, will be necessary to refine our understanding of water consumption.

Due to the wide range of factors that influence water consumption, specifying an appropriate statistical model is challenging. Most obviously, as the human ecological perspective recognizes clearly, ecological context will play an important role in resource use. Thus, it is important to take into account the water resources available in each nation. However, data on water availability, as with water withdrawals, is of poor quality. Furthermore, the connection between water availability and consumption is complex. The abundance of water resources likely has contradictory effects on water consumption. For example, arid nations may need more water for irrigation than well watered nations, but may also be forced to conserve water due to supply limitations. Contrarily, nations with abundant water supplies may not need to conserve water due to its abundance, but also may not need to irrigate extensively due to natural precipitation. This complexity is furthered by a global agri-food production system that often ignores ecological limits, and, thus, very dry regions often become major crop producers.

Furthermore, water resources such as rivers, streams, and groundwater typically do not follow geo-political boundaries. Therefore, many nations share the same water resources (Gleick 2004; Postel 1996). Water drawn upstream can reduce the availability of water downstream. This creates obvious specification issues for cross-national models. As a result, determining the water availability of a nation and controlling for such factors can be problematic. We use the estimates of water resources provided in Gleick (2004) to control for availability, since they are the best available, while recognizing the limitations of these estimates.

Another challenging aspect of model specification is that water use in different economic sectors is likely driven by different forces, and water consumption in one sector is almost surely not independent of water consumption in another. Thus, it is important to specify a model so that it incorporates the interconnections between different sectors. Our solution to this problem is to estimate a simultaneous equation model, using three-stage-least-squares regression, with two endogenous variables: freshwater withdrawals used in agriculture (typically the sector with the greatest water consumption), and freshwater withdrawals used in all other sectors (non-agriculture), both measured in per capita terms (Gleick 2004). The structure of the model is presented in Figure 1.

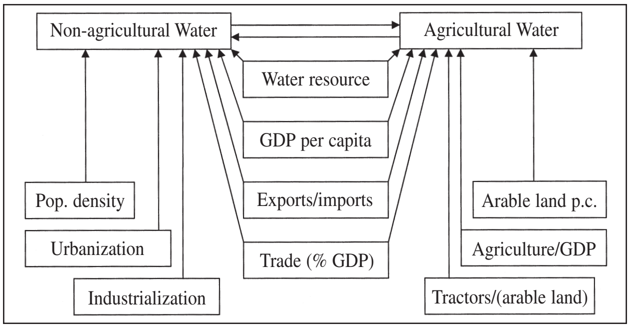

Figure 1. Structure of Model

To incorporate the connections between water consumption in different sectors, agricultural water use is conceptualized as effecting non-agricultural water use, and vice versa. Due to the bi-directional link between the two endogenous variables, in order to estimate the model (i.e., for the model to be identified) it is necessary for each endogenous variable to have at least one exogenous variable that can be reasonably conceptualized as influencing it but not the other endogenous variable. As can be seen in Figure 1, the structure of our model meets this requirement.

In selecting exogenous variables, we sought to include variables that indicate major structural features of societies that may reasonably be expected to affect water use. In particular, we sought to include indicators of ecological context, demographic structure, scale of the economy, structure of the economy, technological development, and connection to the global economy. These are the major factors identified by human ecologists and political economists as driving national-level environmental impacts (York et al. 2003a; Jorgenson 2003). In our model specification, both agricultural and non-agricultural water withdrawals are conceptualized as being influenced by water availability per unit of land area, GDP per capita, the export-import ratio, and the volume of trade (exports and imports combined) as a percentage of GDP. The trade variables are key indicators of globalization, and GDP per capita is an indicator of economic development and modernization (see Table 1 for a full list of variables and their sources).

In addition to the factors conceptualized as influencing both types of water withdrawals, non-agricultural water withdrawals are conceptualized as being influenced by population density, the percentage of GDP coming from the industrial sector, and urbanization (percentage of the population living in urban areas). Population density and urbanization are regarded as major factors that influence patterns of water consumption throughout the world (UNESCO-WWAP 2003). These factors are important indicators of, respectively, the amount of land area from which water resources are drawn and to which they may be applied and the level of institutional modernization. The industrialization variable is also a good indicator of modernization, and, as discussed above, industry is a significant consumer of fresh water.

Agricultural water use is conceptualized as being influenced by arable land area per capita, the percentage of GDP coming from agricultural production, and tractors per unit of arable land area—the latter being an indictor of the mechanization of production. Arable land per capita is an important biophysical variable in that it controls for the extensiveness of agricultural production, while the GDP in agriculture variable indicates nations' economic dependence on agriculture production.

We included all nations in our analysis for which complete data are available. Data for the endogenous variables are from 2000. We use a one year lag for the exogenous variables, which are, therefore, from 1999. All variables in our models are in natural logarithmic form. In addition to helping control for skewed distributions, this approach allows for interpretation of coefficients as elasticities, where the coefficient indicates the expected percentage change in the dependent variable for a 1% change in the independent variables (York et al. 2003b). This approach is also consistent with the widely used STIRPAT model (Dietz and Rosa 1994; York et al. 2003a; 2003b).

Results

Results of our analysis are presented in Table 2.[6] Since the R^2 is not calculable with a simultaneous equation model in the same manner as with OLS, we present the "R^2", which is the squared correlation between the predicted and observed values for each endogenous variable, as a measure of goodness of fit. For non-agricultural water, only three variables have significant effects: agricultural water use, GDP per capi-

Table 1. Summary of the Dependent and Independent Variables

Dependent Variables	*Description*	*Transformation*	*Data Source*
Agricultural water, p.c.	Annual freshwater withdrawals in m^3 per person for agricultural use (water withdrawals per capita multiplied by the proportion of withdrawals for agriculture). Estimated for year 2000.	Logged	Gleick (2004)
Non-agric. water, p.c.	Annual freshwater withdrawals in m^3 per person for industrial and domestic use (water withdrawals per capita multiplied by the proportion of withdrawals for industrial and domestic use). Estimated for year 2000.	Logged	Gleick (2004)
Independent Variables	*Description*	*Transformation*	*Data Source*
Water resource/land	Average freshwater resources in a country (m^3/year) divided by land area. Typically includes renewable surface water and groundwater supplies, including surface inflows from other countries. Estimated for year 2000 based on data for various years.	Logged	Gleick (2004), World Bank (2005)
Population density	Total population divided by land area.	Logged	World Bank (2005)
Arable land per cap.	Arable land (in hectares) divided by population. Includes land defined by the FAO as land under temporary crops, temporary meadows for mowing or for pasture, land under market or kitchen gardens, and land temporarily fallow. Land abandoned as a result of shifting cultivation is excluded.	Logged	World Bank (2005)
GDP, per capita	Gross domestic product per capita—Constant 1995 U.S. dollars.	Logged	World Bank (2005)
GDP in industry (%)	Percentage of gross domestic product in the industrial sector including manufacturing.	Logged	World Bank (2005)
GDP in agric. (%)	Percentage of gross domestic product in the agricultural sector.	Logged	World Bank (2005)
Urbanization (%)	Share of the total population living in urban areas.		World Bank (2005)
Tractors/arable land	The number of wheel and crawler tractors (excluding garden tractors) in use in agriculture divided by arable land area.	Logged	World Bank (2005)
Exports/imports	Value of all goods and other market services provided to the rest of the world divided by value of all goods and other market services received from the rest of the world.	Logged	World Bank (2005)
Trade (% GDP)	Sum of exports and imports of goods and services measured as a share of gross domestic product.	Logged	World Bank (2005)

All variables are from 2000

Table 2. Influences on Agricultural and Non-Agricultural Freshwater Water Withdrawals (cubic meters) per capita, circa 2000

	Non-Agricultural Water	*Agricultural Water*
	Coefficient (S.E.)	Coefficient (S.E.)
Agricultural water, p.c.	1.078 (.250)***	
Non-agric. water, p.c.		.833 (.463)†
Water resource/land	.097 (.095)	-.084 (.099)
Population density	.018 (.075)	
Arable land per cap.		.046 (.222)
GDP, per capita	.631 (.153)***	-.577 (.160)***
GDP in industry (%)	.053 (.185)	
GDP in agric. (%)		.015 (.079)
Urbanization (%)	.056 (.399)	
Tractors/arable land		.039 (.237)
Exports/imports	-.487 (.517)	.488 (.475)
Trade (% GDP)	.979 (.325)**	-.918 (.268)**
Constant	-9.171 (3.015)**	8.598 (3.072)**
N	124	124
"R^2"	.418	.274

† p<.10, ** p<.01, *** p<.001 Two-tailed tests
Simultaneous Equation Model (three-stage least squares) estimates of elasticity (all variables are in natural logarithmic form)

ta, and trade (see Table 2). The finding that the amount of water used in agriculture is positively associated with the amount used for non-agricultural purposes suggests that these two types of water use do not necessarily compete with each other (at least not at the aggregate-level, although they may at the local), but are rather synergistic. Water development for agricultural purposes may well stimulate water development for non-agricultural purposes, and vice versa.

The finding of a significant positive effect from GDP per capita indicates that economic growth is associated with greater non-agricultural water withdrawals. The coefficient indicates that each 1% increase in GDP per capita is associated with a .631% increase in non-agricultural water use, an inelastic relationship. Similarly, overall volume of trade, an indicator of connection to the global economy, has a positive effect. These two findings clearly suggest that modernization and globalization, at least of the economic variety, contribute to the expansion of non-agricultural water use.

The surprising finding that the availability of water resources is not significantly associated with non-agricultural water use may be due to the complexity of the connection between availability and use that we discussed above. Population density also does not have a significant effect. Note that we have already controlled for the absolute size of the population by using per capita values. Thus, this finding does not indicate that demographic factors do not matter, but it does suggest that the amount of land area relative to the number of people does not have a substantial influence on water withdrawals for non-agricultural uses. The fact that industrialization and urbanization do not have significant effects is perhaps surprising, since industry and urban centers are sites of considerable water use. It is also noteworthy that the export/import ratio does not have a significant effect, given that the volume of trade does. This last finding suggests that connection to the global economy is the key influence, rather than the nature of that connection.

The agricultural water side of the model adds further insight into the structural effects on water use. The use of non-agricultural water has a positive effect on agricultural water use, although it is only significant at the .10 level. This adds further support to the contention that there is a synergistic relationship between water development for agricultural use and that for non-agricultural purposes. In contrast with the finding for non-agricultural water use, GDP per capita has a significant negative association with agricultural water use, indicating that each 1% increase in GDP per capita is associated with a .577% decline in agricultural water use. This finding is most likely due to the qualitative changes in the economy that come with economic growth. As with GDP per capita, trade has an effect on agricultural water use opposite to that which it has on non-agricultural water use: Higher levels of trade correspond with significantly less water withdrawals for agricultural use.

As with the non-agricultural side of the model, lack of significant effects from several independent variables is noteworthy. Once again, water resource availability, the land to population ratio (arable land in this case), economic structure, and export/import ratio do not appear to be influential. Nor does the number of tractors relative to arable land, an indicator of the capital and technological intensity of agricultural production, appear to have an effect on water use.

Note that we have also estimated the model including a quadratic term for GDP per capita to test for a non-monotonic relationship with water withdrawals. The quadratic was not significant for either agricultural or non-agricultural water withdrawals, suggesting that the log-linear term is the appropriate specification. Likewise, in a model with a quadratic of urbanization included, the quadratic term does not have a significant effect on either endogenous variable.

These findings taken together point to how modernization and globalization not only affect the scale of water use in nations, but also how water is used. Economic development is associated with relatively lower water use in agriculture but with higher use in non-agricultural sectors of the economy. It is important to recognize that declines in agricultural water use in affluent nations may come at the expense of increasing water consumption in other less affluent nations, where the burden of agricultural production is shifted. Since, unlike affluent nations, less developed nations cannot necessarily afford to rely on agricultural production in other nations, economic growth in low income nations may not in fact be associated with a shift of water use away from the agricultural sector.[7] Similar to the findings regarding GDP per capita, connection to the global economy, as indicated by trade volume, is associated with more non-agricultural water use and less agricultural water use, suggesting that trade globalization leads to a shift in water use across economic sectors.

Discussion and Conclusion

This cross-national investigation into the structural drivers of water consumption initiates a sociological discussion on a vitally important concern for all societies. Our findings suggest that economic development and international trade are key factors influencing water consumption within nations. Nevertheless, these relationships are complex. Some difficulties may arise from the problems associated with gathering and recording data on water resources. As we point out above, there are a variety of issues that must be considered when analyzing these data. However, this preliminary study does begin to outline the form of water consumption in the modern world-system.

There are a few surprising findings as well as non-findings in this analysis. The lack of a significant finding for an association between the availability of water and the use of water is perplexing. Presumably there is an association of some type between water supply and water withdrawals. The complexity of this relationship clearly still needs to be worked out and a better description of the ecological context, such as good measures of rainfall, may help. However, the importance of socio-structural factors as main drivers of water use stands out. The association between agricultural and non-agricultural water withdrawals may stem from the fact that if nations have developed infrastructure to supply water for industry this can enhance access to water for agriculture, and vice versa. The finding that neither industrialization nor urbanization has a significant effect on non-agricultural water withdrawals is surprising, since industry is a major user of water as are urban centers. These results may suggest that non-agricultural water use is both spread throughout the economy and geographically diffuse.

The results related to the trade variable are in need of further investigation, where the volume of trade is positively associated with non-agricultural water use and negatively associated with agricultural water use, while the export/import ratio has no significant effects. These finding may be due to the fact that the trade variable is likely driven by high value non-agriculture commodities. Therefore, nations that have a high percentage of GDP in trade are consuming high levels of water for industry, but may not be using a lot of water for agricultural production. This could be explained by the lower dollar value of agriculture products. This is likely related to the finding that GDP per capita is negatively associated with water withdrawals in agriculture, but is positively associated with non-agricultural water use.

These findings could suggest that water intensive agricultural production is shifted to the poorest countries, as wealthier countries reallocate their water use away from agricultural production. That is to say, nations that have a higher GDP per capita tend to use less water in agriculture, but more water in non-agriculture. The same is true of nations in which trade makes up a greater portion of GDP. The implications of this can be profound as it may indicate that core nations are able to import "virtual water" (Postel 1996) from the periphery through the processes of global food production.

This is exploratory work aimed at encouraging a discussion and stimulating more research on this topic. We have encountered a variety of difficult issues in the analysis of these data. We hope that future work will begin to address these challenges and further elucidate our understanding of water consumption. Better overall measures of water withdrawals and supply would greatly improve the validity of future studies. While this is a technical problem that is not easily solved, we are hopeful that improved methods and record keeping will enhance the quality as well as quantity of data on water supplies and use. As more data become available, time-series analysis would do much to further our understanding of the social structural dynamics at work here. In addition, more refined division of non-agricultural water consumption into multiple sectors may help to increase the validity of the analysis. Future research may also consider the value of qualitative analyses and case study research. Detailed case studies can be used to identify the specific processes and mechanisms by which water withdrawals are determined. This might allow for a more comprehensive understanding of the interrelationships between socio-structural processes and water consumption.

Freshwater is a finite resource that must be used with care. A variety of socio-structural factors are having an impact on freshwater use, and freshwater resources are being stressed throughout the world. This water stress will in turn have significant implications for local populations that need this precious resource for survival. As water is essential to life and its reproduction, understanding the forces that drive water use and affect its availability is a necessary part of developing strategies to deal with problems of environmental and social sustainability.

Endnotes

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2. E-mail: rfyork@uoregon.edu
3. Water stress is defined by the Organization for Economic Co-Operation and Development (OECD 1998) as occurring when the share of a water reserve's average annual levels is below reference minimum levels. An annual supply of 1,700 cubic meters per person is considered the threshold for meeting water requirements for agriculture, industry, energy and the environment within a nation. Analysts consider water availability below 1,000 cubic meters per person to be a state of "water scarcity" (UNDP 2006).
4. While it would be worthwhile to consider the effects of pollution as well as water withdrawals, global data on water pollution are limited. Thus, we focus on withdrawals here, but recognize the need for future analyses of water pollution. See Jorgenson (2007) for the effects of foreign direct investment on the emissions of organic water pollutants in less developed countries.
5. Oil has high value per unit of mass, while water has low value. It is important to note that we are focusing on water for agriculture and other large scale uses, rather than drinking water, which in the form of bottled water can have a fairly high value to mass ratio. Interestingly, this value can, depending on the market, be more than oil. It should also be noted that drinking water makes up a very small portion of total global water withdrawals.
6. Mutlicollinearity does not appear to be a serious problem in the models. In an OLS regression model of the non-agricultural side of the full model, the mean variance inflation factor (VIF) is 1.56 and the highest is 2.44, and for the agricultural side of the model the mean is 2.36 and the highest is 4.07. Since it is generally accepted that multicollinearity is not a serious concern unless VIF values exceed 10 or even 20, these low values indicate the absence of problems with multicollinearity. Likewise, there does not appear to be a problem with outliers. An examination of the distribution of residuals points to only one outlier, Papua New Guinea. If this case is dropped from the analysis, the results are substantively unchanged, indicating that it is not overly influential. Thus we retain it in the models. We have also examined scatter plots of the relationship of each endogenous variable with the exogenous variables affecting it, and the relationships generally appear to approximate linearity, indicating that the specification is reasonable.
7. Note that making inferences about the effects of growth over time based on models using cross-sectional data is inherently problematic. Thus, although we discuss in various places the estimated effects on water use from growth in GDP per capita (or other variables), these estimated effects should be looked upon with due caution, since they are based on the association between water use and GDP per capita in a cross-section, not a time-series.

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